

Some Principles of Synthetic Ecosystems

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ABSTRACT

This position paper explains and illustrates three principles for the design, implementation, and operation of agent-based systems that ERIM CEC has found helpful in the “synthetic ecosystem” approach to real-world agents.

Keywords

Environment, situated intelligence, dynamics, simulation.

1. INTRODUCTION

A distinctive feature of the approach to real-world agents at ERIM CEC is our use of techniques inspired by artificial life. We view an agent-based system as a “synthetic ecosystem,” and seek to exploit numerous techniques that have been observed in naturally-occurring agent-based systems [4]. This position paper explains three principles associated with this approach, and illustrates them from ERIM CEC projects. These principles are::

- Use the environment as an integral part of the system.
- Pay attention to the emergent dynamics of system behavior.
- Simulate, simulate, simulate.

2. USE THE ENVIRONMENT

Twenty years ago, Herb Simon [14] observed that an agent’s behavior is a function not just of the internal structure of the agent, but of the structure and behavior of the environment in which it exists. This insight leads us to a philosophy of system design that seeks to engineer not only the agent community but also the environment in which it is to operate.

This principle is gaining prominence in the robotics community, in which it has recently been termed “ecological balance” [12]. We have found that it can also be applied effectively in software, for example, through synthetic pheromones. Natural insects coordinate their actions by depositing chemical markers in the environment, where physical processes of aggregation, evaporation, and diffusion act upon them. These processes form an intimate part of the information processing conducted by the insects. Aggregation of deposits from different insects is a form of

reinforcement learning at the community level. Evaporation provides a form of truth maintenance by removing obsolete information. Diffusion generates a flow field that coordinates the actions of different insects. The ADAPTIV project [7] uses pheromone dynamics in a synthetic environment to manage the execution of air tasking orders. We used similar mechanisms in Cascade [10, 11] to construct a self-routing material handling system. Our paper [9] and demonstration at Agents 2000 provide further insight into the potential of these mechanisms.

3. PAY ATTENTION TO DYNAMICS

Much research in agents is descended from classical artificial intelligence (AI). One objective of classical AI was the construction of a single human-level intelligence that could pass the Turing Test. This background has led naturally to a focus on the capabilities of individual agents that coordinate their actions through high-level symbolic communications. An implicit focus in much of this work is that a design focus on individual behaviors is sufficient to ensure the appropriate behavior of a system composed of those behaviors.

Another inspiration for agents is artificial life (ALife). In this tradition, the initial focus is on the overall ecosystem in which a variety of species interact. Researchers seek to define the behaviors of the individual agents in order to explain the overall behavior of the ecosystem. It has become axiomatic in this community that the whole is more than, and qualitatively different from, the sum of the parts: a flock is not a big bird, and a traffic jam is not a big car. System behavior “emerges” from the interactions of the individual agents with one another and (as noted in the previous section) with the environment.

The researcher’s stance toward agents is different from that toward the system. Agent behavior can be designed, but system behavior must be observed and analyzed. Historically, statistical physics was developed to account for the *emergence* of the characteristics of an aggregate from the behavior of the individual entities of which it is composed, and the *dynamical behavior* of that aggregate. It offers a rich and mature set of formal mathematical concepts and tools that we extend to understand related phenomena in agent-based systems. These tools, and the mindset that accompanies them, permit the detection and management of a wide range of behaviors and pathologies to which conventional agent approaches are not attuned [6].

Our dynamical analysis of sensor information in a manufacturing facility for specialty vehicles enables us to characterize the behavior of agents (manufacturing workstations) remote from the point at which information is collected [3]. Similar techniques applied to a model of a supply chain in the DASch project [5] have identified unexpected but commercially important behaviors that must be managed in a practical system. In the AORIST project [8], we will apply these techniques to monitor and control

conventional agent architectures for complex military applications such as electronic countermeasures and logistics.

4. SIMULATE, SIMULATE, SIMULATE

Abstractly, it is all well and good to assert that researchers design agents but observe systems. In serving a customer with real-world problems, we must find a way to take control at the system level, and design overall behavior as well as individual agent behavior. Methods for designing systems with emergent behavior are all variations on “generate and test.” We iteratively guess at individual behaviors that we think may yield the system behavior needed, observe the system behavior in simulation, and assess the difference between where we are and where we want to be. The process may be guided manually, or automatically (by some stochastic search procedure such as a genetic algorithm, particle swarm optimization, or simulated annealing). In every case, it is critical that we be able to construct and manipulate executable models of the system, with a rich array of tunable “knobs” that can be adjusted to support unforeseen circumstances.

Our early recognition of this problem led to the development of the XSpec® modeling system [1, 13], which permits the integration of multiple modeling modes (e.g., individual agent behavior, queueing behavior of tasks between agents, and kinematic behavior of physical mechanisms). Recently, we have made extensive use of the Swarm modeling environment developed at the Santa Fe Institute [2]. In one engagement, two competing teams independently implemented a specification of a semiconductor fab provided by a major chip vendor. One team consisted of six programmers on the staff of a software company that sells a major agent development environment, writing in their environment. The other was a single ERIM programmer, using the Swarm system for the first time. The Swarm model was completed first, and after validation became the primary tool used by the chip vendor to guide subsequent design of a scheduling system for their fab. The difference in productivity in this case can be traced to the comprehensive support in Swarm for simulation-specific concerns, such as emulating asynchronous behavior, rich robust random number facilities, data gathering and logging, and easy probing of agent variables during experimentation. Swarm is not a credible tool for the development of a fielded system, but it is an excellent environment for the extensive simulation that we have found to be necessary in developing synthetic ecosystems.

5. SUMMARY

ERIM has found the synthetic ecosystem approach fruitful in designing and implementing agents for real-world applications. Our experience encourages us to use the environment as an active part of the system, to pay careful attention to dynamical models of emergent system-level behavior, and to give simulation and modeling a central position in our projects.

6. ACKNOWLEDGMENTS

The projects mentioned in this paper are funded by a variety of government and industrial sponsors, including DARPA and NIST. The opinions expressed in this paper are those of the author, and do not necessarily reflect the positions of the funders. The ERIM CEC vision for synthetic ecosystems is being realized by the CEC’s agent team, which includes Steve Brophy, Sven Brueckner, Mitch Fleischer, Olga Gilmore, Jorge Goic, Bob Matthews, Murali Nandula, Jon Schneider, John Sauter, Tee Toth-Fejel, and Ray VanderBok. Our work in dynamics and

simulation is done in collaboration with Bob Savit and Rick Riolo of the University of Michigan. Sven Brueckner will represent the group at the workshop.

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